

(19)



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(11)

EP 0 570 124 B1

(12)

## EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention  
of the grant of the patent:  
02.01.1997 Bulletin 1997/01

(51) Int Cl. 6: G02B 6/12

(21) Application number: 93303232.8

(22) Date of filing: 26.04.1993

(54) Integrated nonlinear waveguide spectrometer

Integriertes, nichtlineares Wellenleiterspektrometer

Spectromètre en forme d'un guide d'onde non-linéaire intégré

(84) Designated Contracting States:  
DE FR GB

(30) Priority: 08.05.1992 US 881021

(43) Date of publication of application:  
18.11.1993 Bulletin 1993/46

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- JOURNAL OF LIGHTWAVE TECHNOLOGY. vol. 9, no. 7, July 1991, NEW YORK US pages 906 - 917 D. VAKHSOORI ET AL. 'Inegrable semiconductor optical correlator, parametric spectrometer for communication systems' paragraphs I-IV
- JOURNAL OF LIGHTWAVE TECHNOLOGY. vol. 7, no. 10, October 1989, NEW YORK US pages 1530 - 1539 C. H. HENRY ET AL. 'Glass waveguides on silicon for hybrid optical packaging'

EP 0 570 124 B1

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**Description****Technical Field**

5 This invention pertains to an integrated nonlinear waveguide spectrometer.

**Background of the Invention**

10 Optical spectrometers are waveguide devices that use counter-propagating  $\chi^2$  nonlinear guide interaction to produce a required chromatic dispersion. In these devices, a reference guided mode interacts with a counter-propagating input infrared signal to generate a surface-emitting sum-frequency signal. The angle by which the up-converted visible signal is radiated is a function of the difference in the wavelength of the reference guided mode and the input signal. By fixing the reference wavelength, the frequency spectrum of the input signal is mapped to an angular spectrum of the up-converted signal in the far-field. The physical principle of the nonlinear parametric waveguide spectrometer is shown in Figs. 3 and 4. The nonlinear guide acts as a grating in a conventional spectrometer. Two counter-propagating waves, one being a reference mode and the other an input signal, interact and generate surface-emitting sum-frequency 15 signal radiating out of the top surface of the guide with an angle that is defined by the principle of momentum conservation. If one of the counter-propagating beams (reference beam) has a fixed wavelength, the frequency spectrum of the other counter-propagating beam (input signal) is mapped to the angular spectrum of the sum-frequency signal in the far-field. For example, see R. Normandin et al. "Monolithic, Surface-Emitting Semiconductor Visible Lasers and 20 Spectrometers for WDM Fiber Communication Systems", IEEE Journal of Quantum Electronics, Vol. 27, No. 6, June 1991, pages 1520-1530, and D. Vakhshoori and W. Wang, "Integrable Semiconductor Optical Correlator Parametric Spectrometer for Communication Systems", Journal of Lightwave Technology, Vol. 9, No. 7, July 1991, pages 906-917 (see preamble of claim 1).

25 A structure of a nonlinear guide which would be useful for generating green or blue light from radiation injected into the nonlinear guide was suggested by D. Vakhshoori et al. Conference on Lasers and Electro-Optics Technical Digest, Series 1991, (Optical Society of America, Washington, D.C.) Vol. 10, page 134, R. Normandin and R. L. Williams, Conference on Lasers and Electro-Optics Technical Digest Series 1991 (Optical Society of America, Washington, D.C.) Vol. 10, page 136, D. Vakhshoori et al., "Blue-Green Surface-Emitting Second Harmonic Generation of (111)B 30 GaAs", Applied Physics Letters, Vol. 59, No. 8, 19 August 1991, pages 896-898, and D. Vakhshoori, "Analysis of Visible Surface-Emitting Second-Harmonic Generators", Journal of Applied Physics, Vol. 70, No. 10, 15 November 1991, pages 5205-5210. Such a structure would include a multilayer structure consisting of paired alternating compound semiconductor layers, each layer in a pair having different composition than the other layer in the pair. However, it is still desirable to provide the nonlinear parametric spectrometer with an imaging system which could map the near-field 35 to far-field on compound semiconductor substrates.

**Summary of the Invention**

40 In the invention as set out in the claims a nonlinear parametric waveguide spectrometer is integrated with a waveguide focusing mirror. The waveguide spectrometer uses nonlinear counter-propagating  $\chi^2$  interaction to simulate the action of a grating and produce the required chromatic dispersion. To map the near-field to far-field and separate 45 different wavelength components, an organic-dielectric (e.g. a polyimide/SiO<sub>2</sub>) guide and a 45° RIE etched mirror were fabricated to simulate a concave focusing integrated mirror. The measured spot size at the focal plane of the mirror was about 0.7 μm corresponding to about 0.16 nm (1.6 Angstroms) spectral resolution in agreement with the theoretical prediction. The device has good spectral resolution; however, actual conversion efficiency is smaller than the theoretical 50 prediction. The converted signal should be, theoretically, in the order of 0.1 mW, when 100 mW of reference and input prediction. The converted signal should be, theoretically, in the order of 0.1 mW, when 100 mW of reference and input signal are used. Even with the low signal power level, the integrated device may be of use in applications that can take advantage of the visible output and do not require high power conversion efficiency, (i.e. integration with silicon PIN detectors and circuits where 1.5 μm and 1.3 μm infrared signals cannot be detected.)

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**Brief Description of the Drawing**

55 FIG. 1 discloses a top view of a schematic representation of an integrated spectrometer with curved GaAs/AlGaAs ridge guide and polyimide/SiO<sub>2</sub> slab guide having at opposite ends of the slab guide curved mirrors positioned at 45° to the plane of the ridge guide;

FIG. 2 discloses a cross-sectional side view of a schematic representation of the integrated spectrometer, in which the 45° angle mirrors couple the surface light into and out of the polyimide/SiO<sub>2</sub> slab guide;  
FIGS. 3 and 4 indicate how frequency spectrum of an input signal is mapped to angular spectrum of an up-converted

signal in the far-field;

FIG. 5 discloses a schematic representation of a ridge guide with counter-propagating reference mode of a fixed wavelength and input signal of different wavelengths; and

FIG. 6 discloses a schematic representation of two spots corresponding to blue signal at the focal plane; which result from an interaction of a reference wavelength with two different Ti-Sapphire laser wavelengths.

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### Detailed Description

In an exemplary integrated optical device a nonlinear parametric waveguide spectrometer was integrated with an organic-dielectric waveguide. Forty-five degree angle mirrors etched by Reactive Ion Etching (RIE) were fabricated at both ends of the waveguide to allow the surface light generated by the nonlinear ridge guide to be reflected parallel to the surface and coupled into the organic-dielectric waveguide. In a preferred embodiment, an integrated nonlinear waveguide spectrometer with resolution of .16 nm (1.6 Å) was formed on a 4mm by 7mm GaAs substrate by integrating 10 nonlinear periodic GaAs/AlGaAs ridge guide structure having a 2mm long circular section with a 4mm long polyimide/SiO<sub>2</sub> waveguide.

The integrated optical device is shown schematically in FIGS. 1 and 2 of the drawings, with FIG. 1 being the top view of the integrated optical device, and FIG. 2 being the cross-sectional side view of the integrated optical device. For illustration purposes, dimensions of the integrated device are not drawn to scale.

The integrated optical device, denoted generally by numeral 10, includes a crystalline compound semiconductor substrate, 11, multiquantum well region, 12, including a ridge guide, 13, a dielectric layer, 14, and an organic polymer material layer, 15, provided at opposite ends with 45° mirrors, 16 and 17. Dielectric layer 14 and organic layer 15 form an organic-dielectric waveguide, denominated generally as 18. The dielectric material has a lower index of refraction than the organic material and forms a cladding layer for the organic-dielectric waveguide.

The integrated optical device is fabricated upon substrate 11 having region 12 formed by a plurality of thin layers of alternating composition. The fabrication includes etching in region 12 a pair of trenches, 19, so as to define an isolated ridge guide 13, depositing dielectric layer 14 over an upper surface, 20, of region 12 and in trenches 19, and depositing, over an entire surface, 21, of dielectric layer 14, layer 15 of an optically transmissive organic polymeric material. The slab-like organic-dielectric waveguide 18 is formed by defining outlines of the waveguide on the organic layer and etching the organic layer to a desired form.

Ridge guide 13 was defined by dry-etched trenches 19 to preserve the wafer planarity. Except for the trenches, the wafer is kept planar to facilitate subsequent fabrication of the organic-dielectric waveguide 18 and the 45° mirrors 16 and 17. Ridge guide 13, shown in dashed lines in FIG. 1, consists of a circular arc, 23, in the middle section, and straight sections, 24, at the opposite ends. Small circular arcs may smoothly interconnect circular arc 23 with straight sections 24. In the exemplary embodiment, substrate 11 is of GaAs and region 12 and ridge guide 13 are of GaAs/AlGaAs multilayer, multiperiod structure. Each period is formed by a thin layer of GaAs and a thin layer of Al<sub>x</sub>Ga<sub>1-x</sub>As, wherein x ranges from 0.7 to 1. The thickness of each layer is equal to one-half the wavelength ( $\frac{\lambda}{2}$ ) of the visible light generated in the ridge guide. In the preferred embodiment, the dielectric material is SiO<sub>2</sub> (n = 1.47), and the organic material is polyimide (n = 1.6) forming a polyimide/SiO<sub>2</sub> waveguide. Substrate 11 is about 150µm thick, region 12 is about 1.5µm thick, trenches 19 are 1-2µm wide and about 2µm deep, ridge guide is 2-3µm wide and about 2 µm high, the dielectric layer is about 0.5µm thick, and organic layer 15 is 2-3µm thick. The whole device is about 4 by 7 mm in size, with waveguide 18 being 4 mm long and approximately 2 mm wide. Mirrors 16 and 17 are defined by circular arcs similar to the circular arc of the ridge guide. The circular arcs have a 4mm radius of curvature. The 45° mirrors are etched by Reactive Ion Etching (RIE) in a manner similar to the technique described by L. A. Coldean and J. A. Rentschler in "Directional Reactive-Ion-Etching of InP with Cl<sub>2</sub> Containing Gases", Journal of Vacuum Science Technology, Vol. 19, No. 2, July/August 1981, pages 225-230.

In operation, optical radiation at different wavelengths is supplied into opposite ends of ridge guide 12 so that it counter-propagates into mutually opposite directions. One radiation, denoted a reference radiation  $\omega_0$ , which enters the ridge in one direction, is maintained the same, while the radiation provided from the opposite direction may be injected at a whole range of different wavelengths. Due to the nonlinearity of the ridge guide, a sum-frequency signal is directed into an upward direction toward 45° mirror 16 where it is bounced off 90° into organic layer 15 of the organic-dielectric waveguide 18 and propagates parallel to surface 20 or 21 in the direction of mirror 17 where, at the opposite end of the waveguide 14, the radiation is again deflected. As the up-converted signal 22 from the ridge guide couples into the organic-dielectric waveguide by the reflection off 45° mirror 16, it will form a circular phase front and will focus to a point in a focal plane 4mm away in the waveguide. At that focal plane, another 45° mirror 17 is used to couple the light out of the surface of the waveguide for detection. Direction of propagation of the radiation out from the optical waveguide is determined by the direction and angle of inclination of mirror 17. Since, in this case, the mirror is at 45° to the plane surface of the waveguide, the radiation will be deflected into an upward direction, where it may be detected. A negative 45° mirror may be used to couple the signal back toward surface 19 for detection with integrated detector

array at the focal plane, at or on the substrate.

The resolution of a conventional spectrometer is defined as the change in the input wavelength that shifts the spatial position of the signal from its peak to its first minimum. In this case, for a focusing mirror, e.g. 16, apertured by a 2mm long nonlinear ridge guide, e.g. 13, the angle subtended at the center of the mirror by the spatial separation of the peak and the first minimum of the signal at the focal plane is:

$$\delta\theta_f = \frac{\lambda_s}{nd} = \frac{0.5\mu m}{(1.6) \cdot (2000\mu m)} = 1.6 \times 10^{-4} \text{ rad} \quad (1)$$

where  $\lambda_s$ , n, and d are the sum-frequency wavelength, effective index of the polyimide/SiO<sub>2</sub> waveguide and the aperture of the curved mirror, respectively. On the other hand, the change in the radiation angle due to a change in the input wavelength (Fig. 3) is:

$$\begin{aligned} \theta_r &= \frac{\beta_o - \beta}{K_{\omega_o + \omega}} \\ \Rightarrow \frac{\delta\theta_r}{\delta\lambda} &= \frac{-\lambda_o}{n_s(\lambda_o + \lambda)^2} [(n + n_o) - (\lambda + \lambda_o) \frac{\delta n}{\delta\lambda}] \\ \Rightarrow \delta\theta_r &\approx \frac{\delta\lambda}{\lambda} \end{aligned} \quad (2)$$

where  $\lambda$ ,  $\lambda_o$ , n,  $n_o$ ,  $n_s$  are the input fundamental and reference wavelength, the effective index of the GaAs/AlGaAs ridge guide for the input and reference beams and the effective index of the polyimide/SiO<sub>2</sub> waveguide for the sum-frequency signal respectively. The third line of Equation 2 is obtained by approximating the values of the above parameters for the case of  $\lambda = \lambda_o = 1.0\mu m$ . The resolution of the spectrometer is then estimated to be:

$$\delta\theta_f = \delta\theta_r$$

$$\Rightarrow \delta\lambda = 16 \text{ nm (1.6 \AA)} \quad (3)$$

The measured output from mirror 17 was recorded on a black and white negative. In Fig. 6 are shown schematically two dots which represent the visible blue signal radiating out of the 45° mirror 17 and located at the focal plane of the circular mirror. Laser light from Nd:YAG was used as the reference beam  $\omega_o$  with wavelength  $\lambda_o = 1.064\mu m$ . A tunable Ti-Sapphire laser light was used as the input signal  $\omega_1$  and  $\omega_2$  with wavelengths  $\lambda_1 = 0.9734\mu m$  and  $\lambda_2 = 0.9724\mu m$ , respectively. The recording was made by first tuning the tunable laser to  $\lambda_1 = 0.9734 \mu m$ , sending the reference beam and the first input signal beam into opposite ends of the ridge guide, exposing the film to the up-converted signal, and then without moving the film, tuning the tunable laser to  $\lambda_2 = 0.9724 \mu m$  and re-exposing the same film to the new up-converted spot at its new position. The up-converted signals from  $\lambda_1$  and  $\lambda_2$  are spectrally 1nm apart and the spots are spatially 4μm separated at the focal plane. The signal spot size (FWHM) was measured to be ≈0.7μm for each of the two wavelengths which corresponds to a spectral resolution of 16 nm (1.6 Å) in close agreement with the theory. Some small residual spots (not shown) were present around the two main peaks. These are probably the results of multiple reflections and possible deviation of the curved GaAs/AlGaAs nonlinear waveguide from its ideal circular arc. The coupling loss from the nonlinear ridge guide to the organic-dielectric waveguide and the propagation loss of this waveguide at the wavelength of the blue up-converted signal seems to be large; thus, the power of the signal was much less than the value predicted by the theory. The signal should be, theoretically, in the order of 0.1 mW when 100 mW of reference and input signal are used. Nevertheless, since the signal from the integrated structure is visible, the device may be of use in applications requiring integration with silicon detectors and circuits, i.e. integration with silicon PIN detectors and circuits where 1.5μm and 1.3μm infrared signals cannot be detected.

The integrated spectrometer with nonlinear GaAs/AlGaAs ridge guide was grown on (100) GaAs substrates. This means that for the surface-bound sum-frequency generation, both TE and TM modes should be excited. This actually is an advantage for the nonlinear parametric waveguide spectrometer since by coupling the reference beam as the TM mode and the input signal as the counter-propagating TE mode, no second harmonic generation to the first approximation should exist. The symmetry of (100) surface thus reduces the background visible radiation and prevents the nonlinear mixing of the different frequency components of the input signal.

## Claims

1. An integrated optical device comprising upon a substrate (11), a nonlinear parametric waveguide spectrometer (13) in the form of a ridge waveguide,  
 5 CHARACTERIZED IN THAT

a central portion of said nonlinear waveguide forms a circular arc (23) with a preselected radius of curvature, and in that

10 an elongated organic-dielectric waveguide (18) is positioned above and transverse to the nonlinear waveguide, said organic dielectric waveguide being in the form of an elongated slab of organic material overlaying a thin dielectric layer (14), the dielectric layer having a lower index of refraction than the organic material to act as a bottom cladding layer for the organic material, the opposite ends of said organic-dielectric waveguide (18) being defined by two mirrors (16,17), each mirror being in the shape of a surface that is inclined at 45° to the normal of the substrate and following a circular arc having the same radius of curvature as the circular arc of said central portion (23), the first mirror being positioned above said circular arc of said central portion of said ridge waveguide and being angled so as to reflect visible radiation emanating from the upper surface of the central portion of said ridge waveguide into said organic-dielectric waveguide, the second mirror being angled so as to deflect radiation propagating in said organic-dielectric waveguide out of the surface of the waveguide for detection, the center of curvature of each mirror lying in the plane of the other mirror, so that the radiation reflected from said first mirror is focused onto said second mirror.

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 25 2. The device of claim 1, wherein said ridge guide has a multiperiod structure comprising a plurality of pairs of compound semiconductor layers, the composition of one layer in each pair being different from the composition of another layer in the pair.

30 3. The device of claim 2 in which said ridge guide is defined by a pair of trenches (19) formed in the surface of a multiperiod structure (12) on a GaAs substrate.,  
 said multiperiod structure consisting of a plurality of periods comprising alternating layers of GaAs/AlGaAs.

35 4. The device of claim 2 or claim 3 in which each of said pairs of compound semiconductor layers consists of a layer of GaAs and a layer of  $\text{Al}_x\text{Ga}_{1-x}\text{As}$  with  $x$  in the range 0.7 to 1.

5. The device of any of claims 2 to 4 in which the thickness of each compound semiconductor layer is equal to one-half the wavelength of the visible radiation generated in the ridge guide.

35 6. The device of any of the preceding claims in which said slab of organic material comprises polyimide.

7. The device of any of the preceding claims in which said dielectric material comprises  $\text{SiO}_2$ .

40 8. The device of any of the preceding claims in which said mirrors are inclined 45° in the same direction relative to the plane of the ridge guide, so that radiation reaching said second mirror is directed away from the substrate.

9. The device of any of claims 1 to 7 in which the second mirror is inclined 45° in the direction opposite to that of the first mirror, so that radiation reaching said second mirror is directed toward the substrate.

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## Patentansprüche

50 1. Integriert optische Einrichtung umfassend an einem Substrat (11) ein nichtlineares parametrisches Wellenleiter-Spektrometer (13) in der Form eines Rippenwellenleiters, dadurch gekennzeichnet,

daß ein Mittenabschnitt des nichtlinearen Wellenleiters einen kreisförmigen Bogen (23) mit einem ausgewählten Krümmungsradius bildet und,

55 daß ein länglicher organisch-dielektrischer Wellenleiter (18) oberhalb und quer zum nichtlinearen Wellenleiter angeordnet ist, wobei der organisch-dielektrische Wellenleiter die Form eines länglichen Stabs organischen Materials hat, welches über einer dünnen dielektrischen Schicht (14) liegt, wobei die dielektrische Schicht einen niedrigeren Brechungsindex als das organische Material hat, um als Bodenummantelungsschicht für

5 das organische Material zu wirken, wobei die gegenüberliegenden Enden des organisch-dielektrischen Wellenleiters (18) durch zwei Spiegel (16), (17) definiert sind, wobei jeder Spiegel die Form einer Oberfläche, welche unter 45 Grad zur normalen des Substrats geneigt ist, hat und einem kreisförmigen Bogen mit dem gleichen Krümmungsradius wie der kreisförmige Bogen des Mittenabschnitts (23) folgt, wobei der erste Spiegel über dem kreisförmigen Bogen des Mittenabschnitts des Rippenwellenleiters angeordnet ist und so unter einem Winkel verläuft, daß sichtbare Strahlung, die von der oberen Oberfläche des Mittenabschnitts des Rippenwellenleiters ausgeht, in den organisch-dielektrischen Wellenleiter reflektiert wird, wobei der zweite Spiegel so unter einem Winkel verläuft, daß Strahlung, die sich in dem organisch-dielektrischen Wellenleiter ausbreitet, zur Detektion aus der Oberfläche des Wellenleiters reflektiert wird, wobei das Zentrum der Krümmung jedes Spiegels in der Ebene des anderen Spiegels liegt, sodaß die von dem ersten Spiegel reflektierte Strahlung auf den zweiten Spiegel fokussiert ist.

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2. Einrichtung nach Anspruch 1, bei welcher der Rippenwellenleiter eine periodische Mehrfachanordnung hat, die eine Vielzahl von Paaren von Verbindungshalbleiterschichten umfaßt, wobei die Zusammensetzung von einer Schicht in jedem Paar unterschiedlich von der Zusammensetzung der anderen Schicht in dem Paar ist.
3. Einrichtung nach Anspruch 2, bei welcher der Rippenwellenleiter durch ein Paar von Gräben (19) definiert ist, welche in der Oberfläche einer periodischen Mehrfachanordnung (12) an einem GaAs-Substrat ausgebildet ist, wobei die periodische Mehrfachanordnung eine Vielzahl von Perioden mit abwechselnden Schichten von GaAs/AlGaAs umfaßt.
4. Einrichtung nach Anspruch 2 oder 3, bei welcher jedes Paar der Verbindungshalbleiterschichten aus einer Schicht von GaAs und einer Schicht von  $\text{Al}_x\text{Ga}_{1-x}\text{As}$  besteht, wobei  $x$  im Bereich 0,7 bis 1 liegt.
5. Einrichtung nach einem der Ansprüche von 2 bis 4, bei welcher die Dicke jeder Verbindungshalbleiterschicht der halben Wellenlänge der in dem Rippenwellenleiter erzeugten Strahlung entspricht.
6. Einrichtung nach einem der vorstehenden Ansprüche, bei welcher der Stab organischen Materials Polyimid umfaßt.
7. Einrichtung nach einem der vorstehenden Ansprüche, bei welcher das dielektrische Material  $\text{SiO}_2$  umfaßt.
8. Einrichtung nach einem der vorstehenden Ansprüche, bei welcher die Spiegel in der gleichen Richtung relativ zur Ebene des Rippenwellenleiters unter 45 Grad geneigt sind, sodaß Strahlung, die den zweiten Spiegel erreicht, vom Substrat weg gerichtet wird.
9. Einrichtung nach einem der Ansprüche von 1 bis 7, bei welcher der zweite Spiegel unter 45 Grad in der Richtung entgegengesetzt zur Richtung des ersten Spiegels geneigt ist, sodaß Strahlung, die den zweiten Spiegel erreicht, auf das Substrat zu gerichtet wird.

#### Revendications

1. Dispositif optique intégré comprenant, sur un substrat (11) un spectromètre (13) à guide d'ondes paramétrique non linéaire sous la forme d'un guide d'ondes nervuré, caractérisé en ce que
 

une partie centrale du guide d'ondes non linéaire forme un arc (23) de cercle ayant un rayon de courbure présélectionné, et en ce que

un guide d'ondes (18) organique-diélectrique oblong est disposé au-dessus du guide d'ondes non linéaire et transversalement par rapport à celui-ci, ledit guide d'ondes organique-diélectrique étant sous la forme d'une lame oblongue de matériau organique superposée à une couche (14) diélectrique mince, la couche diélectrique ayant un indice de réfraction inférieur à celui du matériau organique afin de jouer le rôle de couche de gainage inférieure pour le matériau organique, les extrémités opposées du guide d'ondes (18) organique-diélectrique étant définies par deux miroirs (16, 17), chaque miroir ayant la forme d'une surface qui est inclinée de 45° par rapport à la perpendiculaire au substrat et suivant un arc de cercle ayant le même rayon de courbure que l'arc de cercle de la partie (23) centrale, le premier miroir étant disposé au-dessus de l'arc de cercle de la partie centrale du guide d'ondes nervuré et formant un angle permettant de réfléchir le rayonnement visible

émanant de la surface supérieure de la partie centrale du guide d'ondes nervuré vers l'intérieur du guide d'ondes organique-diélectrique, le second miroir étant disposé selon un angle permettant de dévier le rayonnement se propageant dans le guide d'ondes organique-diélectrique et sortant de la surface du guide d'ondes en vue de sa détection, le centre de courbure de chaque miroir se situant dans le plan de l'autre miroir, de façon que le rayonnement réfléchi par le premier miroir soit focalisé sur le second miroir.

- 5            2. Dispositif selon la revendication 1, dans lequel le guide d'ondes nervuré présente une structure multipériodique, comprenant une pluralité de paires de couches semi-conductrices composites, la composition d'une couche de chaque paire étant différente de la composition d'une autre couche de la paire.
- 10          3. Dispositif selon la revendication 2, dans lequel le guide d'ondes nervuré est défini par une paire de tranchées (19) formées dans la surface d'une structure (12) multipériodique sur un substrat de GaAs, cette structure multipériodique étant constituée d'une pluralité de périodes comprenant des couches alternées de GaAs/AlGaAs.
- 15          4. Dispositif selon la revendication 2 ou la revendication 3, dans lequel chacune des paires de couches semi-conductrices composites est constituée d'une couche de GaAs et d'une couche d' $Al_xGa_{1-x}As$ , x se situant dans l'intervalle de 0,7 à 1.
- 20          5. Dispositif selon l'une quelconque des revendications 2 à 4, dans lequel l'épaisseur de chaque couche semiconductrice composite est égale à la moitié de la longueur d'onde du rayonnement visible produit dans le guide nervuré.
- 25          6. Dispositif selon l'une quelconque des revendications précédentes, dans lequel la lame de matériau organique comprend un polyimide.
- 30          7. Dispositif selon l'une quelconque des revendications précédentes, dans lequel le matériau diélectrique comprend du  $SiO_2$ .
- 35          8. Dispositif selon l'une quelconque des revendications précédentes, dans lequel les miroirs sont inclinés de 45°, dans une même direction par rapport au plan du guide nervuré, de façon que le rayonnement atteignant le second miroir soit dirigé de manière à s'écartier du substrat.
- 40          9. Dispositif selon l'une quelconque des revendications 1 à 7, dans lequel le second miroir est incliné de 45° dans une direction opposée à celle du premier miroir, de façon que le rayonnement atteignant le second miroir soit dirigé vers le substrat.

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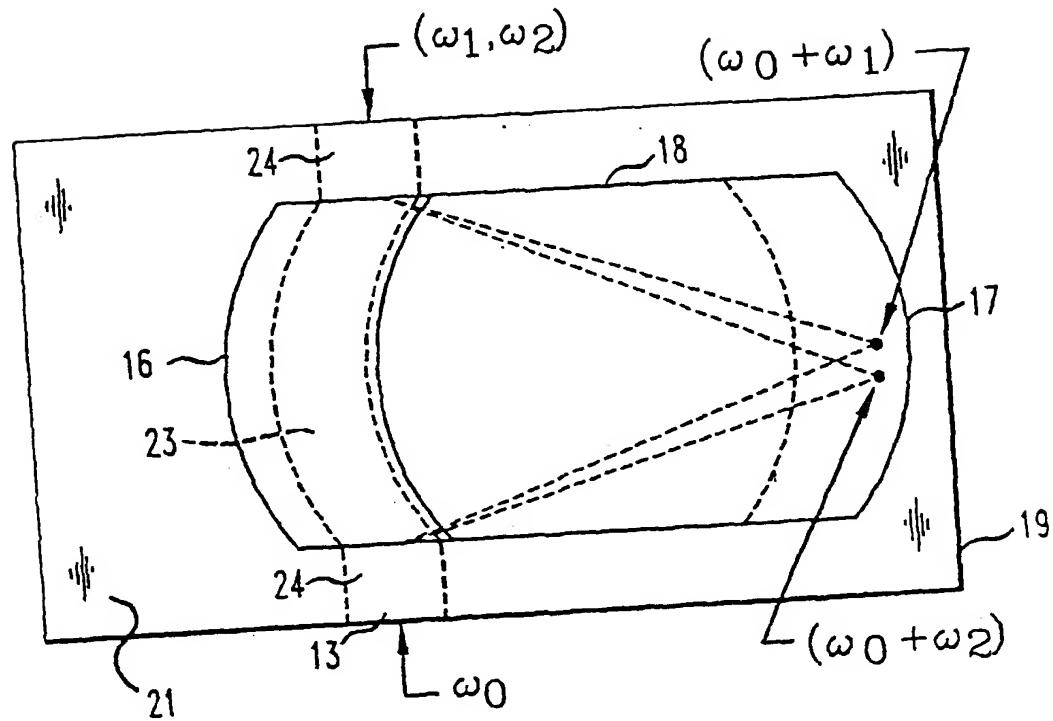
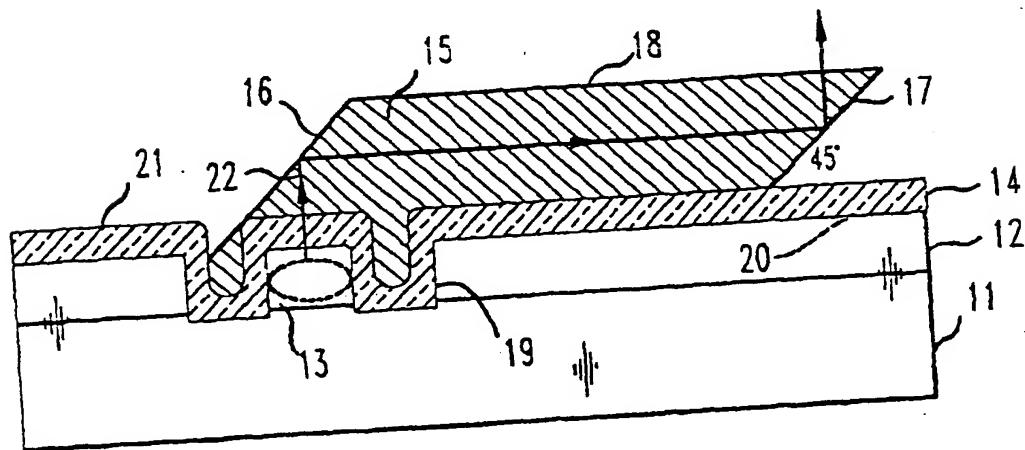
FIG.1 10FIG.2 10

FIG.3

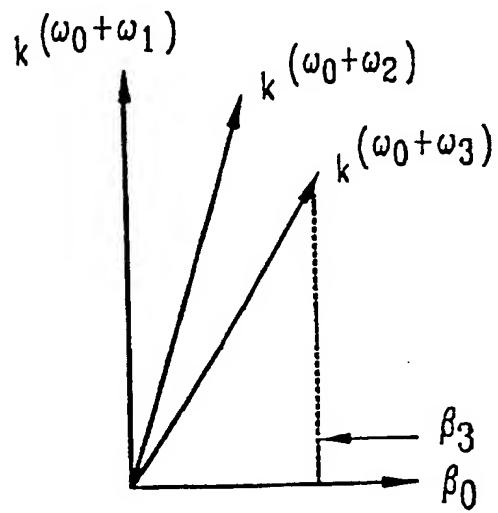
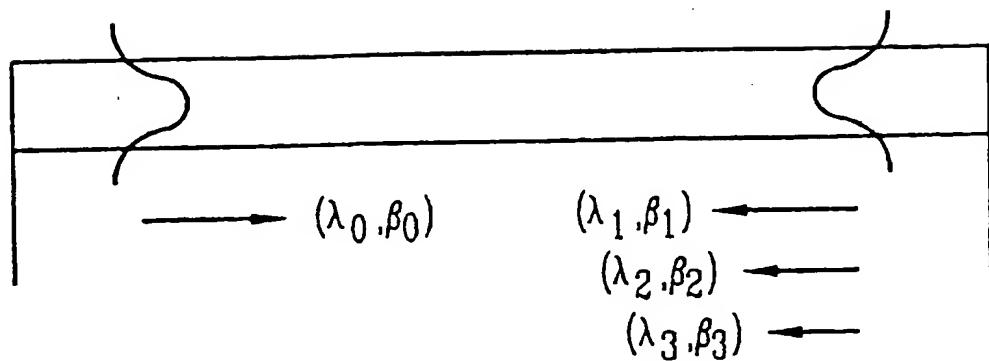


FIG.4

FIG.5

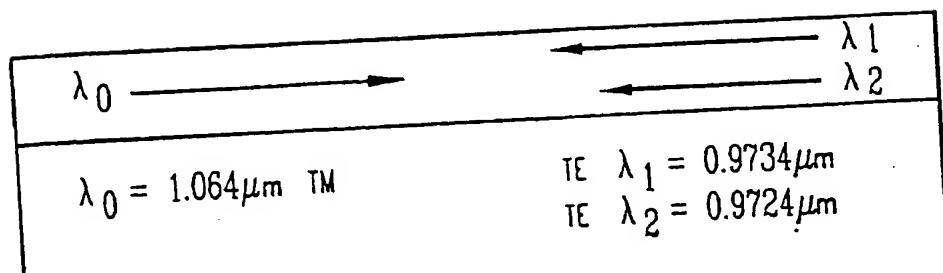


FIG.6

